Original Article

DOI: 10.7860/JCDR/2026/88622.23637

Orthopaedics Section

Evaluation of Posterior Tibial Slope and Anterior Cruciate Ligament Integrity as Risk Factors for Knee Osteoarthritis: A Retrospective Study

CHOCKALINGHAM KASI[1], KV ARUN KUMAR[2], PRADEEP ELANGOVAN[3], SHIVAANI VENKATRAMANAN[4], MD SUGALE RAM[5], K SUDHARSANAN[6], STEVE MERWYN[7]

ABSTRACT

Introduction: Knee Osteoarthritis (OA) is a multifactorial degenerative joint disease with both biomechanical and anatomical risk factors. Posterior Tibial Slope (PTS) and Anterior Cruciate Ligament (ACL) integrity have been individually implicated in joint instability and degeneration.

Aim: To evaluate the association of PTS and ACL status with the radiographic severity of knee OA and investigate their potential synergistic effects.

Materials and Methods: This retrospective study included 334 patients presenting with chronic knee pain, evaluated using lateral radiographs and Magnetic Resonance Imaging (MRI) at a Chettinad Hospital and Research Institute, Kelambakkam, Tamil Nadu, India between March 2021 and March 2024. PTS was measured using the Hudek method, and ACL integrity was categorised as intact, partially torn, or completely torn. OA severity was graded using the Kellgren-Lawrence (KL) system. Multivariable linear regression assessed the predictive value of PTS, ACL status, age, and Body Mass Index (BMI) on OA severity.

Results: Mean PTS increased significantly with OA severity, ranging from 7.9° in KL Grade 0 to 12.1° in Grade 4. ACL integrity declined progressively across KL grades, with 91.1% intact ACLs in KL 0 compared to only 15% in KL 4. A synergistic effect was observed: knees with high PTS (≥10°) and ACL tears had the highest OA severity (mean KL grade=3.3). PTS and ACL status were independent predictors of KL grade (p-value <0.001), along with age and BMI (p-value <0.001).

Conclusion: Increased PTS and ACL deficiency are independent and synergistic risk factors for radiographic knee OA. Early identification of these parameters may inform prognosis and preventive strategies.

Keywords: Biomechanical risk factors, Hudek method, Joint degeneration, Kellgren-Lawrence grade, Radiographic evaluation

INTRODUCTION

Knee OA continues to emerge as a major public health challenge, driven by ageing populations and rising prevalence of metabolic- and injury-related risk factors. Among the biomechanical and anatomical determinants of knee joint degeneration, two interrelated factors- the PTS and the integrity of the ACL- have attracted increasing research interest [1]. The PTS is defined as the sagittal angulation of the tibial plateau relative to the longitudinal axis of the tibial shaft. Multiple biomechanical studies [2,3] have shown that a steeper PTS increases Anterior Tibial Translation (ATT), enhances shear forces across the knee joint during stance and gait, and elevates loads on the ACL or its graft following reconstruction [2]. For example, excess PTS has been associated with higher ACL graft failure rates and increased ligament strain [3]. The altered mechanics produced by a steep tibial slope may accelerate joint degeneration by promoting abnormal tibio-femoral contact stresses, early cartilage wear, and meniscal loading [4].

In parallel, the role of the ACL in maintaining anteroposterior stability and rotational integrity of the knee is well established. ACL deficiency- whether due to rupture, chronic laxity, or failed reconstruction- leads to increased tibial translation, altered kinematics, and accelerated development of knee OA. It is estimated that individuals with an ACL injury have a markedly higher risk of developing OA within 10-20 years despite surgical intervention [5]. Given this background, the interplay between ACL integrity and tibial geometry becomes clinically significant.

Epidemiologically, while there is robust data linking ACL injury and OA progression [6], fewer studies have specifically examined how tibial plateau slope interacts with ligament status to influence OA onset or progression [7]. This research gap underlines the need for studies like this, which aim to delineate whether tibial slope and ACL integrity serve as independent risk factors for knee OA, or whether their effects are synergistic.

Understanding this relationship can have important implications for risk assessment, prevention, and surgical planning, especially in ACL reconstruction and high tibial osteotomy procedures where slope modification may influence long-term joint health. The findings may provide insight into targeted interventions for high-risk individuals and refine the understanding of knee OA pathogenesis in anatomically predisposed populations.

Aim

- To measure the PTS in patients with evidence of knee OA using standardised radiographic techniques.
- To assess ACL integrity (intact, partial tear, or complete tear) using MRI in the same population.
- To correlate PTS and ACL integrity with the presence and severity of knee OA as graded by the Kellgren-Lawrence classification.
- To determine whether PTS and ACL status can serve as independent predictors of OA severity after adjusting for confounding variables such as age and BMI.

MATERIALS AND METHODS

This retrospective study was conducted in the Department of Orthopaedics at Chettinad Hospital and Research Institute, Kelambakkam, Tamil Nadu, India. Data collection period was from March 2021 to March 2024 and data analysis was done from November 2025 to January 2026. The study was conducted after taking approval from the Institutional Ethical Committee (IEC). (IHEC-I/022/10/2025)

Inclusion criteria: Adults aged 18 years and above who presented with knee pain lasting longer than six months and availability of true lateral radiographs of the knee along with MRI scans of the affected knee were included in the study.

Exclusion criteria: A previous history of knee arthroplasty or osteotomy around the knee, presence of any inflammatory pathology, poor radiographic image quality or distorted anatomical landmarks or history of significant trauma resulting in altered knee alignment were excluded from the study.

Sample size estimation: The sample size was calculated using the formula $N = \frac{EVP \times k}{p}$, where EPV (events per variable) was taken as 30 [8], the number of predictor variables (k) was 4 (PTS, ACL status, Age, BMI) and the expected prevalence (p) was assumed to be 36% based on (Webster KE et al.,) [6]. The calculated sample size was 333.3, which was rounded-off to 334.

Study Procedure

A total of 334 patients who presented with knee pain and underwent radiographic and MRI evaluation of the affected knee were included based on the specified eligibility criteria. All data were collected using a structured proforma. Information included demographic details, clinical symptoms, physical examination findings, and radiographic and MRI parameters.

Radiographic Assessment

Radiographic evaluation was performed using true lateral knee radiographs with overlapping femoral condyles. The PTS was measured using the Hudek method [9], which involved the following steps:

1. The longitudinal axis of the tibia was determined by placing two circles or identifying midpoints- one at 5 cm and another at 15 cm distal to the tibial plateau- along the tibial shaft. The centers of these two points were connected to define the tibial anatomical axis.
2. A tangent was drawn along the medial tibial plateau by joining the highest anterior and posterior cortical margins.
3. A line perpendicular to the tibial axis was constructed.
4. The angle between the medial plateau tangent and the perpendicular line was measured and recorded as the PTS, expressed in degrees [Table/Fig-1].

[Table/Fig-1]: Measurement of the Posterior Tibial Slope (PTS).

MRI Evaluation

The MRI assessments were carried out using Proton Density (PD) or T2-weighted sagittal sequences [Table/Fig-2]. The MRI was performed by a single radiologist to avoid inter-rater variability. The ACL was evaluated for integrity and classified as:

[Table/Fig-2]: T2 weighted sagittal sequence MRI of knee showing complete mid substance ACL tear.

- Intact
- Partial tear
- Complete tear [10]

In cases of tears, the anatomical location (proximal, mid-substance, or distal) was documented along with chronic degenerative changes such as atrophic fibres or mucoid degeneration.

Osteoarthritis (OA) Grading

The OA severity was determined using the Kellgren–Lawrence classification [11] based on weight-bearing anteroposterior radiographs. Radiographs were graded from 0 (no OA) to 4 (severe OA), based on the presence of osteophytes, joint space narrowing, subchondral sclerosis, and bony deformity.

STATISTICAL ANALYSIS

Statistical analysis was performed using IBM Statistical Package for the Social Sciences (SPSS) Statistics version 26.0 (IBM Corp., Armonk, NY, USA). Continuous variables were expressed as mean±standard deviation, and categorical variables as frequencies and percentages. The Kellgren-Lawrence grade, being an ordinal variable, was presented as mean with 95% confidence intervals for subgroup comparisons. The association between ACL status and KL grade was assessed using Chi-square test. The association between PTS and KL grade was assessed using the Pearson correlation analysis. Multivariable linear regression analysis was performed to determine the independent effect of PTS, ACL status, age, and BMI on OA severity. A p-value of <0.05 was considered statistically significant.

RESULTS

A total of 334 patients were included in the final analysis. The baseline characteristics of the study population are presented in [Table/Fig-3]. The cohort had a mean age of 52.4±11.8 years with a near-equal sex distribution. The average BMI of 28.6 kg/m^2 falls within the overweight category, which is a known risk factor for knee OA. The distribution of Kellgren-Lawrence (KL) grades shows that the majority of patients (67.9%) had established OA (KL Grade 2-4), providing a sufficient number of cases for analysis against the control group (KL Grade 0-1).

The primary variables of interest were measured across the entire cohort. The results for PTS and ACL status are summarised in [Table/Fig-4]. The mean PTS for the entire cohort was 9.8°, with a wide range from 4.5° to 17.5°, indicating substantial anatomical variation. Regarding ACL status, a majority of knees (60.2%) had an intact ACL, while 39.8% had some degree of ligament failure.

Characteristic	Cohort (n=334)
Age (years) (M±SD)	52.4±11.8
Range	21-78
Sex, n (%)	
Male	178 (53.3)
Female	156 (46.7)
Body Mass Index (BMI), kg/m² (M±SD)	28.6±4.2
Affected Knee, n (%)	
Right	185 (55.4)
Left	149 (44.6)
Symptom Duration (months) (M±SD)	24.5±18.1
Kellgren-Lawrence Grade, n (%)	
Grade 0 (No OA)	45 (13.5)
Grade 1 (Doubtful)	62 (18.6)
Grade 2 (Minimal)	89 (26.6)
Grade 3 (Moderate)	98 (29.3)
Grade 4 (Severe)	40 (12.0)

[Table/Fig-3]: Baseline demographics and clinical characteristics of the study population.

Parameter	Result
Posterior Tibial Slope (PTS),°	9.8±2.5
Range	(4.5° - 17.5°)
ACL Integrity, n (%)	
Intact	201 (60.2)
Partial tear	58 (17.4)
Complete tear	75 (22.4)

[Table/Fig-4]: Distribution of Posterior Tibial Slope (PTS) and ACL integrity.

The stratified analysis demonstrated a clear synergistic effect between ACL integrity and PTS on OA severity. Knees with intact ACL and low PTS had the lowest mean KL grade (1.4; 95% CI: 0.9-1.9). The presence of either high PTS or ACL tear independently increased OA severity (mean KL: 2.1 and 2.5, respectively). However, knees with both ACL tear and high PTS exhibited the highest OA severity (mean KL: 3.3; 95% CI: 2.5-4), indicating a combined detrimental effect [Table/Fig-5].

Group	ACL status	PTS category	n	Mean KL grade	95% CI
1	Intact	Low PTS (<10°)	112	1.4	0.9-1.9
2	Intact	High PTS (≥10°)	89	2.1	1.5-2.7
3	Torn	Low PTS (<10°)	48	2.5	1.8-3.2
4	Torn	High PTS (≥10°)	85	3.3	2.5-4

[Table/Fig-5]: Synergistic effect of ACL status and Posterior Tibial Slope (PTS) on Osteoarthritis (OA) severity (KL grade).
Torn encompasses both partial and complete ACL tears

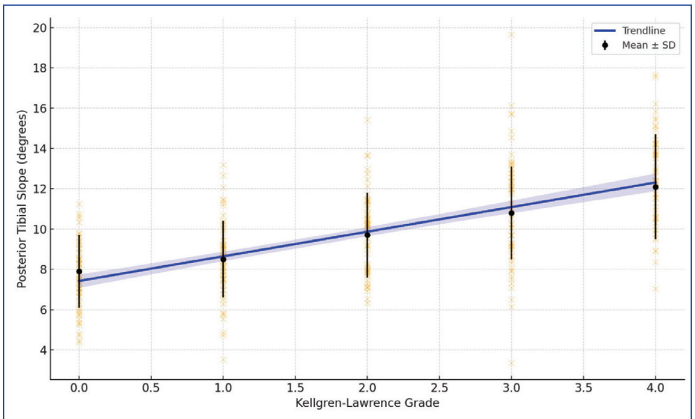
To address the core objectives, the relationships between PTS, ACL status, and KL grade were analysed.

There was a clear and consistent trend of increasing mean PTS with higher KL grades. Patients with no radiographic OA (KL Grade 0) had a mean PTS of 7.9°, while those with severe OA (KL Grade 4) had a significantly steeper mean PTS of 12.1°. This suggests a strong positive correlation between a steeper tibial slope and the radiographic severity of knee OA. (Pearson correlation, r = 0.62, p-value < 0.001) [Table/Fig-6,7].

The integrity of the ACL was strongly associated with OA severity. In knees with no or doubtful OA (KL 0-1), 83.9% to 91.1% had an intact ACL. Conversely, in knees with severe OA (KL Grade 4), only 15% had an intact ACL while 62.5% had a complete tear. The proportion

Kellgren-Lawrence Grade	n	M±SD (°)
Grade 0	45	7.9±1.8
Grade 1	62	8.5±1.9
Grade 2	89	9.7±2.1
Grade 3	98	10.8±2.3
Grade 4	40	12.1±2.6
Overall	334	9.8±2.5

[Table/Fig-6]: Posterior Tibial Slope (PTS) by Kellgren-Lawrence Grade.



[Table/Fig-7]: PTS vs KL Grade.

of both partial and complete tears rises steadily with increasing KL grade. This association was found to be statistically significant (Chi-square test, χ^2= 95.8, p-value <0.001), indicating a strong relationship between worsening OA severity and ACL deficiency [Table/Fig-8].

KL Grade	n	Intact ACL n (%)	Partial ACL Tear n (%)	Complete ACL Tear n (%)
Grade 0	45	41 (91.1)	3 (6.7)	1 (2.2)
Grade 1	62	52 (83.9)	7 (11.3)	3 (4.8)
Grade 2	89	61 (68.5)	15 (16.9)	13 (14.6)
Grade 3	98	41 (41.8)	24 (24.5)	33 (33.7)
Grade 4	40	6 (15.0)	9 (22.5)	25 (62.5)
Overall	334	201 (60.2)	58 (17.4)	75 (22.4)

[Table/Fig-8]: Distribution of ACL status by Kellgren-Lawrence Grade.

A multiple linear regression was performed to predict KL grade based on PTS, ACL status, age, and BMI. ACL status was converted to an ordinal variable (0=Intact, 1=Partial Tear, 2=Complete Tear) for this analysis. The regression model was highly significant and explained 56% of the variance in KL grade (Adjusted R^2=0.56). All four variables- PTS, ACL status, age, BMI were independent and statistically significant predictors of OA severity. For every 1-degree increase in PTS, the KL grade increases by 0.31 points, holding all other factors constant. Similarly, progression in ACL from intact to a partial tear, or from a partial to a complete tear, was associated with an increase in the KL grade by 0.58 points. Age and BMI also proved that older age and higher BMI were also independent risk factors, though their individual effect sizes were smaller than those of PTS and ACL status in this model [Table/Fig-9].

Predictor variable	Regression Coefficient (β)	95% Confidence Interval	p-value
(Constant)	-2.45	(-3.81, -1.09)	<0.001
Posterior Tibial Slope (PTS) (per 1°)	0.31	(0.25, 0.37)	<0.001
ACL Status (per grade increase)	0.58	(0.45, 0.71)	<0.001
Age (per year)	0.04	(0.03, 0.05)	<0.001
BMI (per kg/m²)	0.06	(0.03, 0.09)	<0.001

[Table/Fig-9]: Multivariable linear regression for predictors of KL Grade.
Model Summary: R^2 = 0.57, Adjusted R^2 = 0.56, F-statistic p-value < 0.001.

DISCUSSION

In this retrospective study of 334 knees, the association of PTS and ACL integrity with the radiographic severity of knee OA was evaluated. The key findings were- significant positive correlation between increasing PTS and higher KL grade (mean PTS rising from 7.9° in KL 0 to 12.1° in KL 4); a strong association between worse ACL status (intact → partial tear → complete tear) and increasing OA severity (e.g., 91% intact ACL in KL0, versus only 15% intact in KL4); and a synergistic effect when both risk-factors were present—knees with torn ACL and high PTS (≥10°) had the highest mean KL grade (≈3.3) compared with preserved ACL/low PTS (mean KL≈1.4). Multivariable regression showed PTS (β≈0.31 per degree) and ACL status (β≈0.58 per grade) was independent significant predictors of KL grade, after adjusting for age and BMI (model R^2 ≈0.56).

These results support the hypothesis that both sagittal tibial geometry (as indexed by PTS) and ligamentous stability (via ACL integrity) are meaningful anatomical/biomechanical risk factors for knee OA, and that their combined presence may markedly aggravate degenerative changes. In this cohort, a graded increase in OA severity across ACL status categories was observed, consistent with the notion that ACL disruption predisposes to accelerated degeneration.

It is well-established that ACL injury is a major risk factor for subsequent knee OA. A recent systematic review of reviews reported that ACL injury increases the odds of knee OA by ~6.8× (OR 6.81; 95% CI:5.70-8.13) and after ACL reconstruction by ~7.7× (OR 7.7; 6.05–9.79) compared to uninjured knees [6]. Similarly, Lohmander LS et al., found ~50% of persons with ACL (or meniscus) tear had OA at 10-20 years follow-up [12]. In this cohort, a graded increase of OA severity across ACL status categories, which is consistent with the notion that ACL disruption predisposes to accelerated degeneration. Although this study was cross-sectional rather than longitudinal, the clear association across increasing ACL tear severity supports the existing evidence.

In long-term follow-up of ACL reconstructed patients, Grassi A et al., reported radiographic OA in 73% of patients at ~20 years, with relative risk of 2.8 versus the contralateral knee, and identified meniscal/cartilage injury, older age at surgery and residual laxity as risk factors [13]. The findings add anatomical geometry (PTS) to this risk profile, suggesting that the presence of a steeper tibial slope may further amplify the deleterious effect of ACL disruption on the knee joint.

While much of the prior PTS literature has focused on ACL injury risk rather than direct OA outcomes, the biomechanical plausibility is strong. Shelburne KB et al., used a validated knee-joint model to show that increasing PTS led to increased ATT, tibial shear force, and increased ACL force during standing and walking [14]. In other words, steeper slope causes more anterior tibial shift leading to higher ACL/ligament load and altered joint mechanics. This mechanism provides a rationale for observation of higher PTS being associated with more advanced OA. In the literature, Shi W et al., evaluated PTS and clinical outcomes following a medial-pivot knee prosthesis and noted that steeper PTS may be disadvantageous [15]. However, it should be noted that Driban JB et al., evaluated coronal tibial slope, whereas the present study assessed sagittal posterior tibial slope using the Hudek method. Therefore, direct comparison between the two studies should be interpreted with caution [16]. Mochizuki T et al., also reported that PTS and sagittal alignment may be important factors in OA aetiology [17]. Direct radiographic OA associations with sagittal PTS (as measured by Hudek method) were relatively limited in the literature; and the results therefore contribute novel evidence in this area.

These findings underscore that PTS and ACL status are not simply isolated risk factors but interact in a meaningful way. The stratified analysis is particularly illustrative: knees with intact ACL and low PTS had mild OA (mean KL≈1.4), whereas those with torn ACL and high PTS had severe OA (mean KL≈3.3). This synergy may be explained by the following mechanistic model:

Increased PTS: A steeper PTS increases ATT and shear forces during weight-bearing and gait (as shown by Shelburne KB et al.,) [14]. These forces increase stress on the ACL, articular cartilage, and menisci.

ACL disruption: Loss of ACL integrity compromises knee stability alters tibiofemoral kinematics (more anterior translation, rotational instability) and increases abnormal loading of cartilage and menisci. This has been shown to increase OA risk in long-term follow-up [18].

Combined effect: When both factors are present, the knee is subjected to both inherent anatomical disadvantage (steep PTS) and functional instability (ACL tear). The result is a significantly higher cumulative load on cartilage and menisci over time, accelerating degenerative changes [19].

Modifying factors: Age, BMI, meniscal/cartilage injury and alignment may moderate this relationship; in the regression, age and BMI remained independent predictors though their effect size was smaller than PTS and ACL status. The fact that every 1° increase in PTS was associated with ~0.31 points in KL grade underscores the clinical importance of small variations in slope, especially when combined with ACL compromise [1].

From a clinical perspective, findings in this study suggest that in patients presenting with knee pain and imaging evidence of ACL tear, it may be prudent to measure PTS and consider it in risk stratification for OA. Potential implications: Patients with torn ACL and high PTS may be informed of elevated OA risk and targeted for early conservative interventions (weight control, strengthening, bracing, gait modification) or closer imaging and follow-up. In ACL reconstruction planning, knowledge of a steep PTS may prompt surgeons to consider slope-modifying osteotomy in selected cases, or at least ensure graft placement and rehabilitation are optimised to mitigate augmented anterior shear. The literature on slope-reducing osteotomy is more advanced in revision ACL patients but may eventually extend to OA prevention [7]. In patients with high PTS but intact ACL, preventive measures might still be beneficial; data in this study suggest that even intact ACL + low PTS yields relatively mild OA, but intact ACL + high PTS had increased mean KL (~2.1). Therefore anatomical geometry might warrant vigilance even before ligament failure. Inclusion of PTS and ACL integrity into predictive models for knee OA progression may improve prognostic accuracy beyond traditional risk-factors (age, BMI, alignment, meniscal status).

Strengths of this study include a relatively large sample size (n=334), contemporaneous imaging using consistent radiographic methodology (true lateral for PTS and MRI for ACL status), and formal statistical modelling controlling for age and BMI. The clear dose-response relationship (increasing PTS, worsening ACL status causing worsening KL grade) adds internal consistency.

Limitation(s)

As with any retrospective study, causal inference is limited; one cannot firmly establish that increased PTS or ACL tear caused OA progression rather than simply being associated. Although PTS and ACL status were measured at one time point, the timing of ACL tear relative to OA onset was unknown in many cases, and prior trauma history may not be fully captured. Matched for age and BMI was done, but other important variables (meniscal tears, cartilage injury, limb alignment (varus/valgus), activity level) were not included in regression and may influence OA risk. Outcome measurement was done in radiographic KL grade; functional symptoms, cartilage volume, or progression rate were not assessed. Radiographic OA may not always correlate with symptoms or structural progression. PTS measurement-even using the Hudek method-has inherent variability; although the internal consistency appears good (SD ~2.5°), interobserver/intraobserver variability was not reported. ACL was categorised as intact/ partial/complete tear; and not quantified under laxity, residual function, or time since tear, all of which might influence OA risk. Although the KL grade is an ordinal variable, linear regression was used as an approximation to assess the independent effects of predictor variables, given the near-continuous distribution and for ease of interpretability. However, ordinal logistic regression is statistically more appropriate and may be considered in future analyses. Future research should focus on prospective longitudinal studies to establish a causal relationship between PTS, ACL integrity, and the progression of knee OA. Inclusion of additional biomechanical factors such as meniscal status, limb alignment, and cartilage health may help develop more comprehensive risk prediction models. Advanced imaging techniques and functional outcome measures should be incorporated to better correlate structural changes with clinical symptoms. Interventional studies evaluating the role of slope-modifying osteotomy and early ACL reconstruction in preventing OA progression are warranted. Additionally, larger multicentric studies and the integration of artificial intelligence-based predictive models may enhance risk stratification and guide personalised management strategies.

CONCLUSION(S)

This study adds to the evidence that PTS and ACL integrity are important determinants of radiographic knee OA severity. It also showed that steeper PTS and worse ACL status were each independently associated with higher KL grade, and importantly their combination conferred a markedly higher OA burden compared with either factor alone. Clinicians should consider both tibial geometry and ligamentous stability when assessing knee OA risk. Further longitudinal and interventional work is needed to determine whether modifying these factors can alter the trajectory of knee degeneration.

Acknowledgments

The authors are grateful to their patients for their cooperation throughout the study period.

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PARTICULARS OF CONTRIBUTORS:
1. Junior Resident, Department of Orthopaedics, Chettinad Hospital and Research Institute, Chennai, Tamil Nadu, India.
2. Professor, Department of Orthopaedics, Chettinad Hospital and Research Institute, Chennai, Tamil Nadu, India.
3. Professor, Department of Orthopaedics, Chettinad Hospital and Research Institute, Chennai, Tamil Nadu, India.
4. Junior Resident, Department of Orthopaedics, Chettinad Hospital and Research Institute, Chennai, Tamil Nadu, India.
5. Junior Resident, Department of Orthopaedics, Chettinad Hospital and Research Institute, Chennai, Tamil Nadu, India.
6. Junior Resident, Department of Orthopaedics, Chettinad Hospital and Research Institute, Chennai, Tamil Nadu, India.
7. Junior Resident, Department of Orthopaedics, Chettinad Hospital and Research Institute, Chennai, Tamil Nadu, India.

NAME, ADDRESS, E-MAIL ID OF THE CORRESPONDING AUTHOR:
Dr. KV Arun Kumar,
Professor, Department of Orthopaedics, Chettinad Hospital and Research Institute,
Rajiv Gandhi Salai, (OMR, Chennai), Kelambakkam,
Kanchipuram-603103, Tamil Nadu India.
E-mail: arun5684@gmail.com

PLAGIARISM CHECKING METHODS: [Jain H et al.]
- Plagiarism X-checker: Mar 06, 2026
- Manual Googling: Apr 23, 2026
- iThenticate Software: Apr 25, 2026 (5%)

ETYMOLOGY: Author Origin

EMENDATIONS: 8

AUTHOR DECLARATION:
- Financial or Other Competing Interests: None
- Was Ethics Committee Approval obtained for this study? Yes
- Was informed consent obtained from the subjects involved in the study? Yes
- For any images presented appropriate consent has been obtained from the subjects. Yes

Date of Submission: **Mar 01, 2026**
Date of Peer Review: **Mar 21, 2026**
Date of Acceptance: **Apr 27, 2026**
Date of Publishing: **Jun 01, 2026**